

# Movement Modalities in Consumer VR Applications: a Case Study from Ocean Rift

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**Abstract**—The visceral immersion of VR requires that developers rethink how we design, model and interact with virtual worlds. One of the most important considerations is how the user moves around, and this has led to several movement modalities with various levels of abstraction. In this article we explore movement modalities in VR, and examine how the various systems differ in terms of accessibility, comfort and immersion. We will then provide a case study on how we used these best practices in developing our underwater safari park experience Ocean Rift, which is one of the most popular VR applications across PC and mobile VR.

## I. INTRODUCTION AND BACKGROUND

THE recent emergence of consumer quality VR headsets has led to a veritable renaissance of innovative applications being developed. While gaming remains at the forefront, new applications in entertainment, education, training, commerce, and communication are rapidly being developed.

An exciting aspect of VR development is working with an emerging platform, where best practices are constantly being evolved [1]. One of the most salient challenges is the fundamental question of how to move through the virtual world. As VR has the potential to attract a universal audience, the development of artificial locomotion and interaction techniques must also consider accessibility, and inclusivity.

We motivate this article by examining the issue of VR sickness, and how it closely relates to artificial locomotion. We will then look at the spectrum of movement modalities available to developers, and how each compares in terms of realism, comfort and freedom. We will then provide a case study on how we built upon burgeoning best practices to develop our VR aquatic safari park experience, Ocean Rift [2] (Figure 1).

Cybersickness [3] is closely related to motion sickness, common symptoms include nausea, headaches, sweating, eye strain, disorientation, fatigue and dizziness [4]. There are many factors that influence susceptibility, including age, gender, ethnicity, health, experience and general motion sickness sensitivity [5].

Any kind of artificial locomotion can cause VR sickness. One theory is that this is due to a mismatch between



Fig. 1. Screenshot from Ocean Rift. The Title rock formation is one of the first habitat teleport points of interest.

what the user is seeing (often referred to as *vection*) and what their vestibular system is detecting [6] (known as *sensory conflict theory* [7]). Research also indicates that while mismatches between physical and perceived head rotations can result in nausea, the relationship between motion and VR sickness is more complex [8].

The continuing refinement of HMDs (Head Mounted Displays) has had a significant effect on reducing VR sickness, with low persistence screens, higher frame-rates, larger FOV (Field of View) and positional tracking systems already reducing the rate and severity of symptoms in comparison to earlier devices. However the pervasiveness and seriousness of comfort in VR also requires continued experimentation and refinement of VR control modalities. While there is evidence that users can develop “VR legs” through continued exposure [9], avoiding cybersickness is a priority of developers.

In the following section we will describe various VR movement modalities. We will then explain how we they build on one another to provide a universal experience we developed for Ocean Rift.

## II. CATEGORISING MOVEMENT SYSTEMS

While the VR industry is still in its infancy there are already a diverse range of HMDs available. These HMDs can be divided into two broad categories mobile and tethered. Each has their comparable advantages, disadvantages and associated design considerations.

For the purpose of discussion we can split VR movement systems into four categories (Figure 2), based on

two qualities - the *freedom* of movement the user has within the virtual environment, and the extent that the user's *physicality* is mapped onto the virtual character.

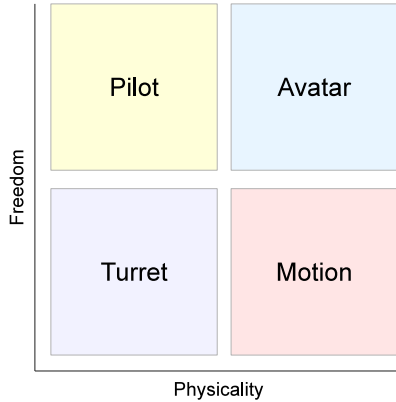


Fig. 2. Diagram of the four movement modalities categories based on their freedom and physicality.

- 1) **Turret:** *low freedom / low physicality* - In a turret system the player is fixed in a specific location and can look around. Most mobile and seated VR applications fall into this category. While Turret systems can afford the player movement around the environment, this is not movement they directly control. For example, a roller coaster simulator would fall into this category.
- 2) **Pilot:** *high freedom / low physicality* - In a pilot system the player is able to freely move around the environment, but this is accomplished using artificial locomotion usually driven by traditional game interfaces. While the player can look around naturally, they are essentially a passenger in a vehicle they control. Movement in artificial locomotion systems can be continuous, by directly moving the camera, or discrete, where the player instantly jumps or 'teleports' from one location to the next.
- 3) **Motion:** *low freedom / high physicality* - A motion system is similar to a turret system, in that the player is typically locked into a single location. However, here the player's position is also tracked where movement within the boundaries of their physical space is tracked and replicated in VR.
- 4) **Avatar:** *high freedom / high physicality* - In an avatar system the player has full freedom of movement around the virtual environment, without concern of the boundaries of the physical world. An example of this would be a room scale system combined with a teleport mechanic, allowing players to move their boundary around the environment. There are some examples of more advanced methods of abstracting the real-world boundary,

such as redirected movement [10] or custom built real world 'sets' that are 1:1 mapped to the virtual space. Both of these type of systems require a large physical space.

While we are in an age of constant innovation in the VR industry, some movement systems have emerged as favourites among developers and consumers alike. The following subsections will provide a short overview of these systems.

#### A. Teleporting

Teleportation has become a popular method of locomotion in VR. This is largely due to its ability to facilitate exploration of a large space while bypassing triggers of VR sickness common in other methods. One of the big advantages of teleportation is that it requires very little control bandwidth. In its simplest form, a user can teleport to a predefined location with a single click of a button. The simplicity of this system makes teleportation an ideal mechanic for using the native control interface of mobile VR, such as the single button available on the Google cardboard. In most cases it is more comfortable for a user to jump ahead rather than spend an extended period in a perceived motion state between locations. The mechanic is also ideal for transporting the user between prescribed points of interest, as while many users will enjoy exploring an environment, providing a set of teleportation destinations can help guide the experience.

#### B. Positional Tracking

Positional tracking is the most intuitive form of VR locomotion, in that it accurately mirrors the user's real world movement, and as a result greatly reduces the chances of triggering sickness. Positional tracking is often combined with a secondary mechanic such as teleportation, enabling the user to reposition their real-world tracking volume without the need for physical locomotion.

There are risks associated with this mechanic, most notably that the user loses track of where they are in the real world and bump into something. However, technology such as the Vive's chaperone and outwards facing camera, or the Rift's Oculus Guardian System both act to display or fade in an outline of the real world when users get too close to their physical bounds reducing the risk.

#### C. Gamepad locomotion

The gamepad represents the most traditional, and best known method of control in video games and virtual

environments. The main advantage of using a gamepad controller in VR is that it allows the user to explore the virtual world fully even if there are significant limitations in available real-world space. However, as previously noted, sensory conflict theory is a widely recognized trigger of VR sickness this makes gamepad based artificial locomotion a contentious issue in VR.

The speed and severity of VR sickness is closely linked to perceived acceleration, where instant changes of speed are preferable [11]. For this reason, the acceleration and deceleration rates in many VR experiences benefit from abrupt transitions between stationary and moving states. This is commonly considered to be a best practice. It is accepted best practice now that all rotational camera motion should come as a direct result of the users head movements.

Users are much more sensitive to artificial motion in directions other than their current facing. For this reason most artificial locomotion systems will also dampen sideways and backwards motion, usually at 50-70% of maximum forward speed.

One caveat to this rule is snap rotation. In snap (also known as ratchet) rotation, a flick of the right analogue stick causes the cameras yaw to instantly (or over a number of frames) snap 30 or 45 degrees left or right. As there is no perceived acceleration or motion, this is quite a comfortable way of virtually rotating the camera, a type of rotational teleport. Snap rotation can be of benefit to people using mobile VR while sitting down, or where free rotation of the body may not be possible.

#### *D. Motion Control*

One of the most unique and exciting aspects of modern VR is the ability to track the user's hands. The HTC Vive and Oculus Touch controllers differ in their approach to motion control, however, in terms of degrees of freedom and general input both function similarly and one control scheme can be emulated by the other. As they are based on natural hand and arm movements, motion control systems are very intuitive, even beginners with minimal instruction and training can quickly start performing complex actions. While motion control systems are generally used for hand interaction (such as picking up objects, or aiming weapons), tracking the users hands also provides developers with a number of novel control possibilities. For example in Ocean Rift the user is able to naturally swim around by performing gestures, which we discuss in in the next section.

### III. OCEAN RIFT: A CASE STUDY IN VR MOVEMENT

Ocean Rift is a VR aquatic safari park that users can swim around and explore at their leisure [2]. The

app is divided into a number of habitats, which range in size from a 12 foot shark cage to three kilometre cubed aquariums. Each habitat is themed around star animals, analogous to zones found in zoos and safari parks. A large habitat will feature many different types of flora and fauna, and various points of interest for the user to discover, including shipwrecks, coral reefs and geological features. Entertainment takes precedence over accuracy in terms of wildlife and terrain composition, though we aim to stay consistent with the habitat theme. However, the app has been used successfully in a number of education and outreach contexts, including as a museum exhibit, and as in a number of schools.

A key feature of Ocean Rift is that all of large animals are virtual creatures capable of displaying the range of motion and dexterity shown by real-life equivalents. A novel animation and behaviour system was developed to realise this idea, based on artificial intelligence and procedural animation techniques. Instead of a typical data-driven approach, where creatures are animated using pre-animated sequences that are blended together, all animation and behaviour in Ocean Rift is calculated live at runtime. As a result we can synthesize interesting, complex, and organic behaviour that is different with every visit.

Ocean Rift was a launch title for the Samsung Gear VR and Oculus Rift, and has been installed on over one million devices. At the time of writing, the Gear VR version of Ocean Rift has as a rating of 4.3 based on over 4500 reviews.

#### *A. Motivation*

One of the main goals we had with Ocean Rift was that it should be suitable and accessible to all ages and experience ranges. Being a launch title for Gear VR and Oculus Rift, the app was likely to be one of the very first VR experiences for many people. As a result, we wanted the user interface and controls to be immediately intuitive, while also giving more advanced users the ability to freely swim around and explore.

The main focus of this case study will be to explain how Ocean Rift was designed to be accessible to people of all ages and levels of expertise, across a wide spectrum of VR devices.

#### *B. Habitat Teleportation*

The most basic method of traversing to and around Ocean Rifts habitats is to teleport. When the user selects a new habitat icon they are transported to the initial teleport location for that habitat. However, in dangerous places such as the prehistoric or great white shark habitat

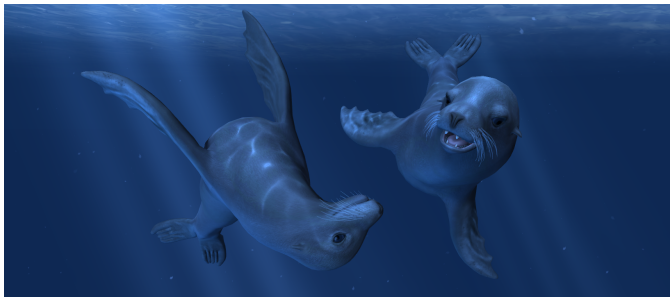


Fig. 3. Screenshot from Ocean Rift's sea lion habitat. Animals in Ocean Rift are animated using state of the art procedural animation techniques so that every visit and encounter is unique.

the primary teleport location will be in a safe place (such as inside a cage). Each habitat has a dozen or more teleportation points which are placed at various points of interest. Users can also cycle their position through inner-habitat teleport locations.

Similar to a real world attraction, each habitat is designed so that there is a main circular path that guides the player through the map. Not all features of a habitat are accessible by teleportation points however, and users are free to swim away and explore the habitat more thoroughly at any time.

Loading a habitat can cause spikes in CPU performance, especially on mobile devices. This can cause the frame-rate to stutter and severely discomfort the user. We use a number of tricks to distract and disguise the loading, designed to cover up these technical hitches while also making the transition as comfortable as possible.

When a new habitat icon is selected, the first thing that happens is a sci-fi teleportation effect envelops the camera, giving the user visual and aural feedback the teleportation process is underway. The UI is disabled during this sequence in order to discourage selection of another habitat mid-load. During the teleportation process the app asynchronously loads the new habitat in the background, and at a critical stage (where CPU spikes are expected) we fade the water to opaque black. We then switch the scene over, and fade back to the new habitats water colour and transparency. Finally, we fade away the teleportation effects and re-enable UI control.

### C. Touchpad Swimming

The Samsung Gear VR comes with an inbuilt touchpad on the right side of the device, positioned at the users temple. The touchpad can detect when the user taps, double taps and swipes. The touchpad only detects relative movement however, and cannot accurately detect the position of the users finger.

We wanted Ocean Rift to be fully explorable using only the touchpad, as Gear VR headsets are not normally bundled with a gamepad. Being a launch title for a high volume mobile VR device like the Gear VR meant the app was likely to be used not only by enthusiasts, but by friends, family and people with no prior experience of navigating virtual environments.

With the current prevalence of touch screen based devices the average user is likely to be more experienced with swiping gestures than any other method of app interaction. Combined with the previously outlined teleportation system and simplified UI, this touchpad control scheme represents the lowest common denominator for interaction and locomotion in Ocean Rift. Users are able to bring up and dismiss the menu, select a habitat and teleport around its various points of interest. In VR, this 'turret' mode of exploring is very engaging in itself, especially in an app like Ocean Rift as procedurally animated creatures like Sea Lions swim up to the player and perform tricks, or a Great White Shark crashes into the protective cage. However after a while most users, especially once accustomed to these systems will want to swim around and explore. In order to accommodate this we developed a novel method of smoothly navigating three dimensional environments using the touchpad.

With the UI inactive, holding a finger down on the touchpad (as opposed to tapping) allows users to swim forwards in the direction they are looking (this is referred to as gaze-directed locomotion). As the direction of forward motion is always the same as where the user is looking, this method of artificial locomotion is unlikely to cause discomfort.

Up and down swipe gestures are used to swim upwards and downwards, while left and right swipes are used to swim sideways. Each swipe is the equivalent of a single stroke of the arms, and so by continuously swiping a person can smoothly swim in that direction. The combination of long press to swim forwards and swiping to change elevation and move sideways allows practically anyone to explore a virtual environment in three dimensions.

### D. Remote Swimming

Instead of a built-in touchpad, the Oculus Go, and Google Daydream platforms are primarily controlled using a remote. The upper third of the remote is a circular touchpad that functions similarly to the Gear touchpad. The remote also has built in orientation tracking. The touchpad controls for Ocean Rift map very clearly onto this control scheme.



### E. Gamepad Swimming

As previously mentioned, the speed and severity of VR sickness onset is closely linked to perceived acceleration in VR, where instant changes of speed are preferable. For this reason, the acceleration and deceleration rates in many VR experiences will have very abrupt transitions between standing still and moving, with little acceleration.

In Ocean Rift, our goal of simulating underwater movement mechanics is largely in antithesis to this, as transitioning between treading water and swimming and vice-versa feels much more realistic when there is a perceived acceleration. In developing a comfortable movement system we found two main techniques that helped avoid the onset of motion sickness. Firstly, our acceleration and deceleration curves are gradual enough that they fall outside the range that commonly trigger motion sickness. Secondly our default movement speed is slow, with a dedicated "swim fast" button that is active only when already at maximum default speed. This two stage acceleration is robust enough that we can even apply a sin curve to simulate a subtle wave-like motion of swim strokes.

Other factors that can aggravate VR sickness include low field of view, viewing angle, and motion parallax, especially at the peripheral of vision. Being underwater our app represents a close to best case scenario in terms of curbing these multiplier effects, due to largely open environments, uniform background color, low visibility and an obscured horizon line.

As mentioned in the previously, Users are much more sensitive to artificial motion in directions other than their current facing. However, in Ocean Rift we use a high lateral damping value of 80%, as the associated aggravating factors such as perceived motion at the peripheral of vision is rare when moving through an underwater environment. Having a high strafe speed allows users to more easily swim alongside animals and orbit around slow moving ones like humpback whales and manatees.

### F. Motion Control

For Ocean Rift we also wanted to support artificial locomotion using motion controllers only. Our first attempt was to simulate real world swimming, where hand motions are used to generate thrust by displacing water. We found that using the controller's trigger as a method of enabling displacement was desirable, allowing the user to control when their arm strokes had any influence on movement. However while coarsely simulating real-world swimming mechanics is possible, we found that

most users prefer a method of locomotion where the hands are used to move through the water in the direction they are gestured.



Fig. 4. Screenshot from Ocean Rift. Oculus Touch motion controllers can be used to comfortably locomote around the environment using natural hand gestures.

Whilst we found artificial locomotion using hand gestures to be a very effective way of moving around in three dimensions, constantly gesturing with hands can become tiring, especially when traversing a large amount of space or over long play sessions. This prompted us to add the ability to turn each hand into a propeller using the grip sensor built into both HTC Vive and Oculus Touch controllers. This feature allows the user to automatically apply thrust in the direction they are pointing using one hand, while the other hand is free to make adjustments using gestures. Furthermore, gripping both controllers firmly allows the user to swim with speed in any direction.

### G. Positional Tracking

On supporting hardware we accommodate positional tracking automatically in Ocean Rift, with the user free to stand up and walk around their tracking volume. A typical example of this could be a user standing up, crouching and walking around the shark cage, while a mobile user would remain (without artificial locomotion) as a turret in the centre of the cage.

This type of locomotion system is commonly used alongside teleportation, where users can move their tracking volume between habitat points of interest at leisure. However it is also compatible with gamepad and motion control swimming.

Research has shown that providing an independent and static background as a visual anchor can help reduce simulator sickness and provide more stability in VR [12]. In order to aid swimming in conjunction with room scale tracking, we (optionally) render an ethereal platform at the position of the real world ground at all times, so that even if the user is in open water there remains a reference point to real world. We can also fade in the bounds of the

tracking volume as a function of the player's speed, so if they are moving quickly we fade in an outline of their surroundings, which can also help curb any discomfort.

#### H. Designing for Movement in VR

Through our experience with Ocean Rift, and our engagement with various VR platforms, and stakeholders we have learnt that the entire experience has to be designed to facilitate intuitive movement. A correctly designed environment can help mitigate some of the challenges of VR while providing the user with a more immersive experience. These are some of the main design tenets we used when creating a new habitat:

- 1) *Direct the player to points of interest* - This helps avoid players feeling lost while maintaining a feeling of exploration.
- 2) *Logical environment design* - A circular design encourages exploration and helps users to figure out where they are based on relative landmarks.
- 3) *Reward exploration* - Placing interesting items and secrets off the beaten track encourages and rewards the player for their exploration.
- 4) *Provide escape* - If players feel trapped or scared it may encourage them to panic, pull the headset off or make quick movements which could trigger motion sickness or accidents in the real world. Predators in Ocean Rift will only attack if the player is in a "danger zone", usually off the beaten track, past several warning signs.
- 5) *Bring activity to the player* - In order to provide an entertaining experience, we ensure that Ocean Rift's star animals seek out the player even if they are stationary.
- 6) *Respect personal space* Encroachment of the players personal space can feel as uncomfortable in VR as it does in the real world. We therefore try to ensure that creatures maintain a safe distance from the player at all times (just within arm's length).

#### IV. CONCLUSION

In this article we have presented an overview of movement modalities in VR, and given examples of best practices across the main platforms and control systems. We also presented a case study of how we developed Ocean Rift, our popular VR aquatic Safari Park experience. We demonstrated how important design decisions need to consider many factors unique to VR, and how burgeoning rules of comfort and accessibility informed the app's design across the UI, environment and tiered movement systems.

Artificial locomotion remains a contentious issue in VR, and is likely to remain so for the foreseeable future. While new genres work within the bounds of what's eminently comfortable (limited to room scale tracking or seated experiences), there will always be a desire to explore large spaces or worlds. We believe that systems like the motion controlled swimming we developed for Ocean Rift are a step in the right direction, as it merges natural gestures with comfortable locomotion through 3D space.

Finally VR software development is very much reliant on hardware. In the last few years positional and hand tracking systems have made many new movement modalities and experiences possible. The next generation of VR devices are likely to facilitate further refinement of comfortable and accessible exploration in VR.

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